Modeling Pulsatile Flow Induced Surface Charge Disturbance In Flow Cytometry Sense Electrodes

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Abstract

Impedance spectroscopy is an established sensing methodology used in microfluidic flow cytometry systems to electrically measure cell characteristics. The fluid transport method used in most flow cytometers is continuous flow driven by external syringe or pressure regulated pumps. An on-chip integrated pumping system utilizing thermal ink jet technology is an attractive alternative that offers tremendous cost and scaling benefits. One of the challenges with this type of integrated pump is the pulsatile nature of the fluid transport, and its effect on the impedance measurement system. Impedance spectroscopy uses the capacitive double layer (CDL) present at the solution-electrode interface to transfer charge between sense electrodes, and it forms an integral part of the impedance sensing network. Since this capacitance is a function of ionic concentration, any change in electrolyte concentration near the electrode surface will also change the CDL and measured impedance value.
COMSOL multi-physics 2D modeling is used to demonstrate the effects of pulsatile flow on the CDL at the sense electrode surface by coupling the Electrostatics, Transport of Dilute Species, and Laminar Flow modules with the Time-domain solver. It is shown that a fluid velocity pulse applied at the inlet of a microfluidic channel disturbs the ionic species equilibrium in the double layer region, thereby altering the electrode surface charge density and effective double layer capacitance value. This capacitance change produces a significant shift in the measured impedance value of the sensing network and can easily corrupt real-time measurement data.
Figure (1) shows the 2D geometry that defines the electrodes and fluidic channel with an overlay of electrolyte potential and fluid velocity streamlines captured at peak fluid velocity time of 10us.
Figure (2) shows the surface charge density change caused by the fluid velocity pulse, resulting in a significant drop in the effective double layer capacitance. This data correlates well with empirical data that shows a sense network impedance increase, caused by a lower electrode CDL value, when flow velocity is suddenly increased in a microfluidic channel.
This multi-physics modeling approach provides an effective way to predict the effects of pulsatile flow on impedance sensing networks and can guide microfluidic channel and electrode design optimization to minimize flow-induced electrical disturbances.

Reference

Martins, D. C., Chu, V., et al. (2013). "Streaming currents in microfluidics with integrated polarizable electrodes." Microfluidics and Nanofluidics, 15(3), 361-376. https://doi.org/10.1007/s10404-013-1153-5

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Figures used in the abstract

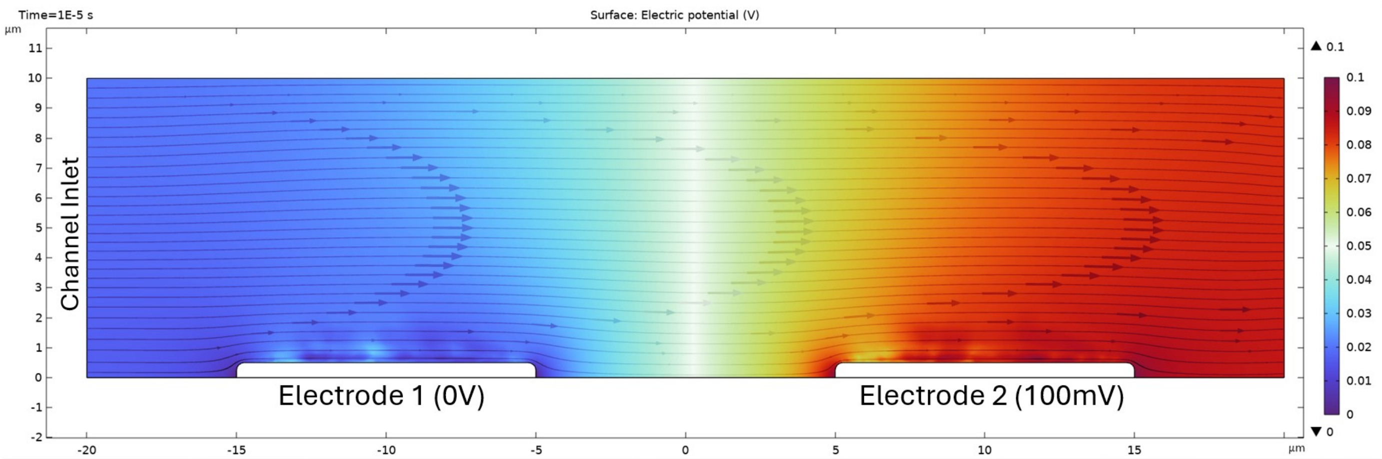

Figure 1 : Figure (1) Electrolyte Potential with Fluid Velocity Streamlines

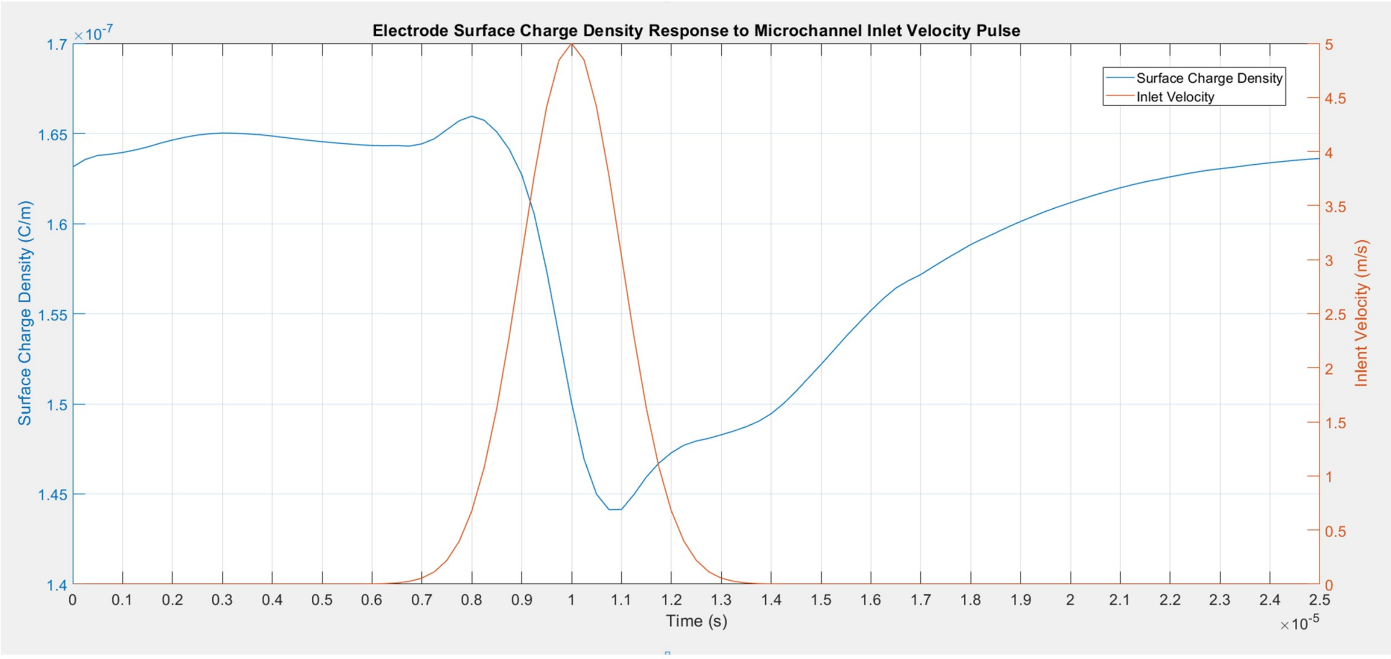

Figure 2 : Figure (2) Electrode Surface Charge Density Response to Inlet Velocity Pulse